A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

NeoBiota 99: 341–362 (2025)
DOI: 10.3897/neobiota.99.153010

Research Article

Invasive species risk assessment in practice: Insights from a survey of practitioners

Susan Canavan[1], Kim Canavan[2,3], Sabrina Kumschick[4,5], Doria R. Gordon[6,7], John R. U. Wilson[4,5], Deah Lieurance[8]

1 School of Natural Sciences, Ollscoil na Gaillimhe–University of Galway, Galway, Ireland
2 Centre for Biological Control, Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa
3 Department of Plant Sciences and Afromontane Research Unit, University of the Free State, Phuthaditjhaba, South Africa
4 Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa
5 Kirstenbosch Research Centre, South African National Biodiversity Institute, Cape Town, South Africa
6 Environmental Defence Fund, New York, NY, USA
7 Department of Biology, University of Florida, Gainesville, FL, USA
8 Department of Ecosystem Science and Management, The Pennsylvania State University, State College, USA
Corresponding author: Susan Canavan (sucanavan@gmail.com)

Abstract

Risk assessment is an important tool in invasive species prevention and management, providing a structured approach to identify and evaluate the risks posed by non-native species. Despite the widespread development of risk assessment and risk analysis (collectively referred to as RA here) methods, there is a lack of information on which methods are used in practice. We conducted a global survey of RA practitioners from diverse regional, professional, and taxonomic contexts to identify the tools and databases used, the qualifications and experience of assessors, and the implementation and accessibility of RA results. 107 responses were received from practitioners focussed on all continents except Antarctica, with the most from the United States and the United Kingdom. Respondents reported using more than 46 different RA tools, with the Fish Invasiveness Screening Kit and the USDA Plant Protection and Quarantine Weed Risk Assessment the most commonly mentioned tools, based on the number of users. Plants were the most frequently assessed taxonomic group and terrestrial species, though representation from all taxonomic groups and systems exist. Respondents listed 107 generally open-access databases that they frequently use to conduct RAs, with the most commonly used sources being the CABI Invasive Species Compendium, occurrence records from the Global Biodiversity Information Facility (GBIF), and taxonomic information from the Integrated Taxonomic Information System (ITIS). Assessors typically had tertiary education, with the majority holding at least a master's degree, though many did not believe that a post-graduate degree was necessary to be an effective assessor. After RAs were completed, assessments were predominantly reported to government agencies. Most finalized RAs included some measure of certainty and were usually publicly accessible, though few included a formal process for stakeholders to comment. Almost all respondents identified the importance of training and certification programs to standardize qualifications for assessors. Based on the views expressed in the surveys we discuss the importance of: (1) training and capacity building, (2) open access databases and FAIR (Findable, Accessible, Interoperable and Reusable) data standards, (3) incorporating stakeholders in the process, and (4) standardisation of tools; if these measures are implemented, they may enhance the consistency, transparency, and effectiveness of RAs of non-native species.

Key words: Alien species, biosecurity, GBIF, impacts, Invasiveness Screening Kit, ITIS, non-native, weed risk assessment

OPEN ACCESS

Academic editor: Ingo Kowarik
Received: 14 March 2025
Accepted: 5 June 2025
Published: 11 July 2025

Citation: Canavan S, Canavan K, Kumschick S, Gordon DR, Wilson JRU, Lieurance D (2025) Invasive species risk assessment in practice: Insights from a survey of practitioners. NeoBiota 99: 341–362. https://doi.org/10.3897/neobiota.99.153010

Introduction

Risk assessments for non-native species aim to predict the potential that species may establish and negatively impact natural and human systems. Risk assessments facilitate systematic evaluation or forecasting of the level of threat non-native species pose pre- or post-introduction. They have become a standard practice in many countries, with agencies and organizations using them to guide management decisions (e.g., EPPO 2011; USDA APHIS PPQ 2020), and consequently, assessments related to species introductions have been incorporated into international trade and environmental policy agendas, quarantine legislation, and procedures at national borders. For example, the International Standards for Phytosanitary Measures (ISPM) and the World Organisation for Animal Health (WOAH) have established standards and guidelines for risk assessments to restrict the movement of pests and protect human and animal health (FAO 2007a, 2007b).

Risk assessment methods vary in design, scope, and intended use, being tailored to different taxa, regions, ecosystems, and pathways. Some focus on screening species for their potential invasiveness, while others provide detailed assessments of specific species, including full impact categorization, pathway analysis, and species distribution mapping. Examples include the Aquatic Species Invasiveness Screening Kit (AS-ISK) for aquatic systems (Copp et al. 2016) and the Australian Weed Risk Assessment (AWRA) for plants (Pheloung et al. 1999). Region-specific assessments include the EPPO framework for Europe (EPPO 2011) and the Canadian Food Inspection Agency (CFIA) pest risk analysis (CFIA 2012). However, there is often a lack of consolidation and continuity among these approaches, with varying terminology (Roy et al. 2018). Terms such as "protocols", "frameworks", "kits", "schemes", and "systems" can incorporate elements of risk assessments to varying degrees, with some terms used interchangeably, though the term "risk analysis" typically encompasses risk assessment, risk management, and risk communication (e.g., FAO 2007a and b; Kumschick et al. 2020b). All of these incorporate a predictive process intended for the management of biological invasions. For the sake of brevity, we will collectively refer to these tools and methods as "RAs".

The peer-reviewed literature includes numerous publications on RAs, offering various perspectives on the utility and function of the process (e.g., Leung et al. 2012; Kumschick and Richardson 2013; Roy et al. 2018; Lieurance et al. 2024). While the development of RA tools is well documented in academic literature, whether and how they are actually used in practice is less clear, as this often takes place in grey literature or internal agency processes and is not systematically tracked (Roy et al. 2018; Dean et al. 2024). As a result, it remains unclear which tools are used, by whom, and for what purposes. Understanding how RAs are applied is important, as previous comparative studies have shown that inconsistent tool use, limited stakeholder involvement, and uneven training can undermine transparency, repeatability, and comparability in outcomes (McGeoch et al. 2016; Roy et al. 2018). Key questions include: Who develops these methods, and who actually implements them? What expertise do practitioners need, and what training should they have? Which taxa and ecosystems are being prioritized for assessment, and which data sources underpin these evaluations? Equally important, particularly for decision-makers and affected stakeholders, is understanding how clearly and effectively RA results are communicated.

In this study, our goal was to gain a practical understanding of the real-world application of RAs as applied to non-native species. We conducted a global survey of practitioners from diverse regional, professional, and taxonomic contexts to identify the tools and databases they use, the qualifications they hold, and how RAs are implemented and reported.

Methods

Survey development

We developed a 29-question survey to gather information directly from risk practitioners, including a list of RA programs (including both risk assessment and risk analysis), databases, and other sources of information, as well as a practical description of RA in practice. The survey was composed of various questions (Table 1; See Suppl. material 1: table S1 for full survey)

Throughout the data collection process, standard procedures of survey design used in similar studies were followed (e.g., Gozlan et al. 2013). The survey was confidential, and respondents' anonymity was maintained. The questions included a mixture of list-all-that-apply, check-all-that-apply, Likert-scaled, multiple choice, and open-ended questions (i.e., fill in the blank), with the survey taking an estimated 10–15 minutes to complete. The survey was approved by the University of Florida's Institutional Review Board, ID #202001808.

We used three approaches to solicit responses. 1) The survey was distributed on 17 November 2020, through two listserv groups: Ecolog-L, hosted by the Ecological Society of America, and Aliens-L, hosted by the Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission. At the time of distribution, Ecolog-L had approximately 27,000 subscribers, and Aliens-L had 1,470 subscribers. Both groups primarily consist of students, academics, and practitioners working in the fields of ecology (Ecolog-L) and invasive species (Aliens-L). 2) The survey was shared on Twitter on 17 November 2020 initially on two main accounts (@ifasassessment and @drdeahlieurance) and then shared from there by other users. The Twitter posts promoting the survey received a combined 16,278 impressions (i.e., times a user was served a tweet in their timeline or search results), excluding impressions from approximately 62 retweets. And 3) direct invitations were sent to corresponding authors of peer-reviewed papers on invasive species risk analysis or risk assessment. These authors were identified through a targeted search, with a focus on improving geographic representation. Efforts focused on reaching out to researchers from underrepresented regions, particularly in Asia and South America, based on preliminary survey responses following the Twitter call, which indicated a deficit from these areas. The survey remained open for responses from November 2020 to March 2021.

Data analysis

All analyses and data visualization were performed using the programming language R (v4.0.4.). To extract the survey results, we used the package 'qualtRics' (Ginn et al. 2024). Responses that were at least 80% complete were included, as this threshold ensured that respondents had answered the majority of questions, while still allowing

Table 1. Overview of survey topics and key findings. This table summarizes the structure and major results of the survey. For the complete list of survey questions and response formats, see Suppl. material 1: table S1.

Theme	Question topic	Results summary
General information		
	Tools used	46 tools identified (Table 2; Fig. 2)
	Geographic scale	Assessments done mostly at the country-level (40%) and regional scale (39%)
	Geographical coverage	89 countries assessed (Fig. 1)
	Taxonomic groups assessed	Predominantly plants (Fig. 3a)
	Ecosystems assessed	Predominantly terrestrial ecosystems (Fig. 3b)
Experience with RAs		
	Length of experience	Most respondents > 5 years' experience (60%)
	Number of RAs conducted (past 3 years)	Most respondents conducted < 10 RAs (44%)
	Time required per assessment	Typically weeks to months
	Organizations represented	Government agencies (48%), research institutions (29%)
Qualifications & Opinions		
	Education level of assessors	Majority hold master's (24%) or doctoral (64%) degree
	Necessary education for effective assessment	Bachelor's degree or lower (52%); Master's degree or higher (39%)
	Availability of training programs	Strong support for formal training and certification programs (73%)
Data and Information		
	Data sources used	107 databases listed, mostly open-access with CABI, GBIF, and ITIS being the most cited (Fig. 4; Suppl. material 1: table S3)
	Data quality & difficulty	Challenges include outdated or incomplete data
Implementation of RAs		
	Peer review included	88% include peer review (internal/external)
	Uncertainty/confidence reported	Included in 93% of assessments
	Public comment period	Rarely included (41% never, 20% always)
	Accessibility of RA results	Usually publicly accessible (40% always, 37.2% occasionally)
	Results used in policy	Frequently inform policy recommendations

for minor omissions that commonly occur in surveys. This yielded 107 usable surveys from the initial 262. We used the longitude and latitude coordinates of the IP addresses to estimate where survey respondents were based and plotted the data using the 'maps' package (Fig. 1). We then mapped the number of RAs conducted per country based on the results of the survey questions (Fig. 1), noting that some respondents may have used Virtual Private Networks (VPNs), reducing the accuracy of these location estimates.

We used Likert scale analysis to summarize and visualize responses to specific survey questions regarding the taxonomic groups assessed, the factors that typically initiate a new RA, and the ecosystems evaluated. Additionally, we summarized the most frequently used databases (those mentioned by more than five respondents) that inform RAs for general, taxonomic, and occurrence information. To illustrate the frequency of database use, we created a heatmap, providing a clear visual representation of the data.

We manually grouped RA tools using two objective criteria: AWRA affiliation and geographic region. First, each RA tool was categorized based on its relationship with the AWRA framework, one of the original and most widely adapted frameworks, into two groups: (1) AWRA or derivative tools, including those that directly implement the original AWRA or are derived from it, either directly or indirectly. Indirect derivation includes tools like the NZAqWRA, and its direct derivatives like the US-AqWRA, a tool originally developed to address limitations of the AWRA for aquatic plants. (2) Non-AWRA tools, developed independently of the AWRA framework.

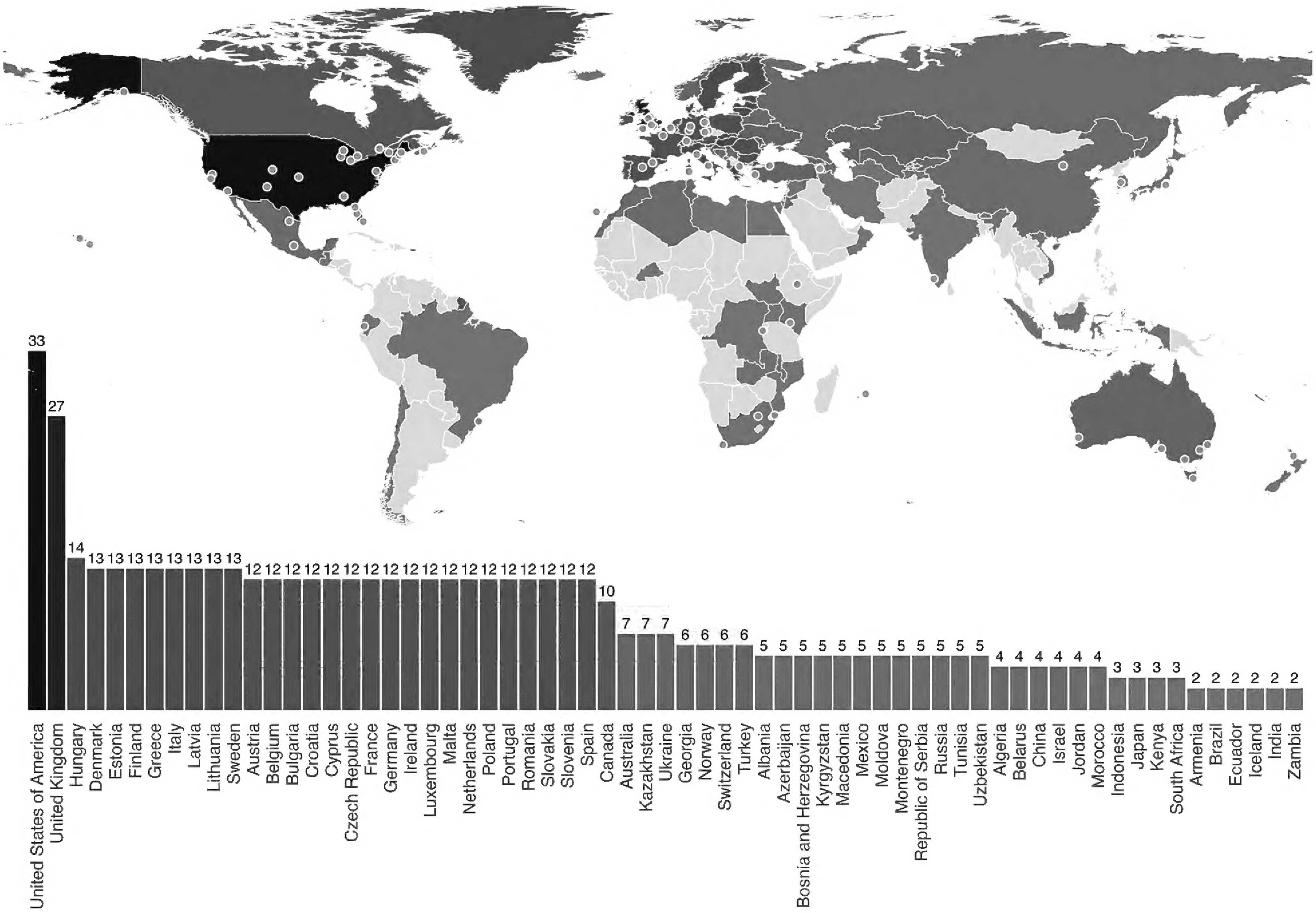

Figure 1. Map of assessed areas and assessor locations. Map showing respondents' locations (red dots; n = 107) and the regions where they have conducted risk assessments and risk analyses (collectively RAs here) (green shaded areas). The bar graph indicates the number of respondents who have produced RAs for each country. This reflects respondent counts, not the total number of assessments. Only countries for which an RA was produced by two or more respondents are shown on the bar graph (an additional 25 countries had RAs produced by only one respondent). The shade of green represents the number of respondents, with darker green indicating higher numbers and lighter green indicating lower numbers. This shading is consistent across the map and the bar graph. Note that if a respondent specified a broad region such as Europe, each country within that region was counted.

This classification allows for an analysis of the influence and adaptation of the AWRA framework across different RA tools. Second, the tools were grouped by the continent in which they were developed and applied. We then counted the number of respondents who mentioned each tool and visualized this classification scheme using a Sankey diagram created with the 'networkD3' package in R (Fig. 2). The diagram illustrates the hierarchical flow from all tools through AWRA affiliation and geographic regions to individual RA tools, with flow widths proportional to respondent counts.

The results of all other questions were summarised in Suppl. material 1: table S3.

Results and discussion

RA methods are increasingly being adapted worldwide to aid the management of invasive species. While RA is well discussed academically, we sought to better understand how it is being applied in practice by asking about the practitioner's experiences; below we discuss the results of the survey on the tools and databases used, the qualifications and experience of assessors, and the implementation and accessibility of the tools used.

Geographic scope of assessments

Our survey gathered responses from 107 assessors, reflecting a global response, albeit with a notable concentration from anglosphere countries and Europe (Fig. 1). The smaller showings from Africa and Asia are consistent with other studies within invasion biology which identify geographic biases (e.g., Pyšek et al. 2008; Nuñez et al. 2022) that may be attributed to language barriers (Nuñez et al. 2022). Because we only shared this survey in English, we will have missed potential respondents. Given the bias toward assessors from anglophone countries and Europe, it is not surprising that the majority of RAs mentioned have been conducted in these regions (Fig. 1), especially in the United States and the United Kingdom. At the continental level, North America accounted for 31% (n = 44) and Europe for 21% (n = 30) of regions assessed, with smaller contributions from Asia (12%, n = 17), Australasia (11%, n = 15), Africa (11%, n = 15), and South America (6%, n = 8). We did note that some assessors indicated that they had assessed multiple countries and regions. We also found examples of regions that have been assessed despite there being no survey respondents located in those countries at the time of the survey, such as countries in North Africa and Central Asia. In terms of the scale, RAs often focus on smaller geographic regions that may not span geopolitical boundaries. This likely reflects the mandates and jurisdictions of the responsible authorities. While such scales are often appropriate, limited coordination across political boundaries may reduce opportunities for early detection and response to widespread invasions. Our findings largely support this trend: assessments were mainly conducted at the country level (n = 53; 40%) or a more local scale (e.g., state, province, territory, county; n = 51; 39%), with fewer at the continental scale (n = 18; 14%).

Successful transnational cooperation is evident in certain regions, such as the European Union's Invasive Alien Species Regulation (Regulation (EU) 1143/2014), which aims to standardize RAs across EU member states. This has led to the creation of the Union List, a centralized list of invasive alien species of Union concern. RAs supporting this list may follow various schemes, including a dedicated EU risk assessment template, national frameworks, or other tools, provided they meet a set of standardized minimum criteria established by the European Commission. The European and Mediterranean Plant Protection Organization (EPPO) has developed widely used tools, especially for plants, that are available in multiple languages and applied in several of its 52 member countries (EPPO 2024). Our survey captured the use of several RAs in European contexts, including Pest Risk Analysis (PRA), Harmonia+, the UK Risk Assessment Scheme, Computer-Aided Pest Risk Analysis (CAPRA) software, and the Invasive Species Environmental Impact Assessment (ISEIA) (See Table 2 for references; Fig. 2).

While our survey captured a range of tools used across Europe and North America, many other regions were less well represented. This skewed geographic distribution may reflect underlying weaknesses in biosecurity practices in these regions, as a paucity of RAs could signal limited capacity for managing biological invasions. Consequently, this not only hampers our understanding of how, why, and when RAs are conducted but also restricts a global comprehension of invasion patterns (Nuñez et al. 2022).

Table 2. List of all risk assessment and risk analysis methods mentioned, and their given acronyms for Fig. 2, used by survey respondents.

Acronym	Full name	Reference
APHIS PPQ-WRA	Animal Plant Health Inspection Service Plant Protection and Quarantine Weed Risk Assessment	Koop et al. 2012
AS-ISK	Aquatic Species Invasiveness Screening Kit	Copp et al. 2016
AWRAM	Aquatic Weed Risk Assessment Model	Champion and Clayton 2000
AWRM	Australian Weed Risk Management	Virtue 2010
CABI	Centre for Agriculture and Biosciences International - International Plant Protection Convention - Pest Risk Analyses Tools	CABI 2019
CAl-IPC PAF	California Invasive Plant Council - Plant Assessment Form	Cal-IPC (n.d.)
CAPRA	EPPO's Computer Assisted Pest Risk Analysis tool	Griessinger et al. 2012
CFIA-PRA	Canadian Food Inspection Agency Pest Risk Assessment	Canadian Food Inspection Agency (2020)
Climate tools	MaxEnt, Climatch, etc.	multiple
CMIST	Canadian Marine Invasive Screening Tool	Drolet et al. 2016
EDRR-ST	Greater Everglades Rapid Response Screening Tool	Romagosa 2018
EICAT	IUCN's Environmental Impact Classification for Alien Taxa	Hawkins et al. 2015
EPPO PRA	EPPO PRA Express/ German Express Risikoanalyse (express PRA)	Brunel et al. 2010
FAO-WRA	Food and Agriculture Organisation - Weed Risk Assessment	Williams 2002
FI-ISK	Freshwater Invertebrate Invasiveness Scoring Kit	Tricarico et al. 2010
FISK	Fish Invasiveness Scoring Kit	Copp et al. 2005
G-WRA	Galapagos Weed Risk Assessment	Rogg et al. 2003
GABLIS	The German-Austrian Black List Information System	Essl et al. 2011
GB-NN-RA	Great Britain Non-Native Risk Assessment	Baker et al. 2008
GISS	Generic Impact Scoring System	Nentwig et al. 2016
GLANSRA	Great Lakes Aquatic Non-indigenous Species Risk Assessment	Davidson et al. 2017
Harmonia+	Harmonia+	D'hondt et al. 2015
HPWRA	Hawaii-Pacific Weed Risk Assessment	Daehler et al. 2004
HS-RRA	Horizon Scanning Rapid Risk Assessment	Roy et al. 2014
INSEAT	Invasive Species Effects Assessment Tool	Martinez-Cillero et al. 2019
IPC-PRA	USDA Imported Plant Commodity PRA Framework	USDA APHIS PPQ 2020
IRAAPA	invasiveness risk assessment of arboreal plants in Armenia	Fayvush et al. 2018
ISEIA	Invasive Species Environmental Impact Assessment protocol	Branquart et al. 2007
MERI	Método de Evaluación Rápida de Invasividad	Mandujano et al. 2021
NTS	Biosecurity New Zealand Pest Risk Analysis	Government of New Zealand MPI 2020
PPQ-WC	PPQ Weed Characterization	Koop Pers. Comm.
PRA	EU template European Commission	EPPO 2019
PRE-A	Plant Risk Evaluator Assessment	Conser et al. 2015
PRE-T	Plant Risk Evaluation Tool	Conser et al. 2015
PT	Predictive Tool	Gordon et al. 2008
RAAT	Risk Analysis for Alien Taxa	Kumschick et al. 2020b
S-WRA	Samoa WRA	Space and Flynn 2000
SEICAT	Socio-Economic Impact Classification for Alien Taxa	Bacher et al. 2018
STAIR	Science-Based Tools for Assessing Invasion Risk	Gantz et al. 2015
UK-RAS-NNS	The UK Risk Assessment Scheme for all Non-Native Species	Baker et al. 2008
USAqWRA	United States Aquatic Weed Risk Assessment	Gordon et al. 2012
VARMS	Post-border vertebrate animals risk management systems	Bomford et al. 2008
VIVRA	Victorian Invasive Vertebrate Risk Assessment	Bomford et al. 2008
VP-PPP	Victorian Pest Plant Prioritisation Process	Weiss et al. 2002
VWRA	Victorian Weed Risk Assessment	Weiss et al. 2002

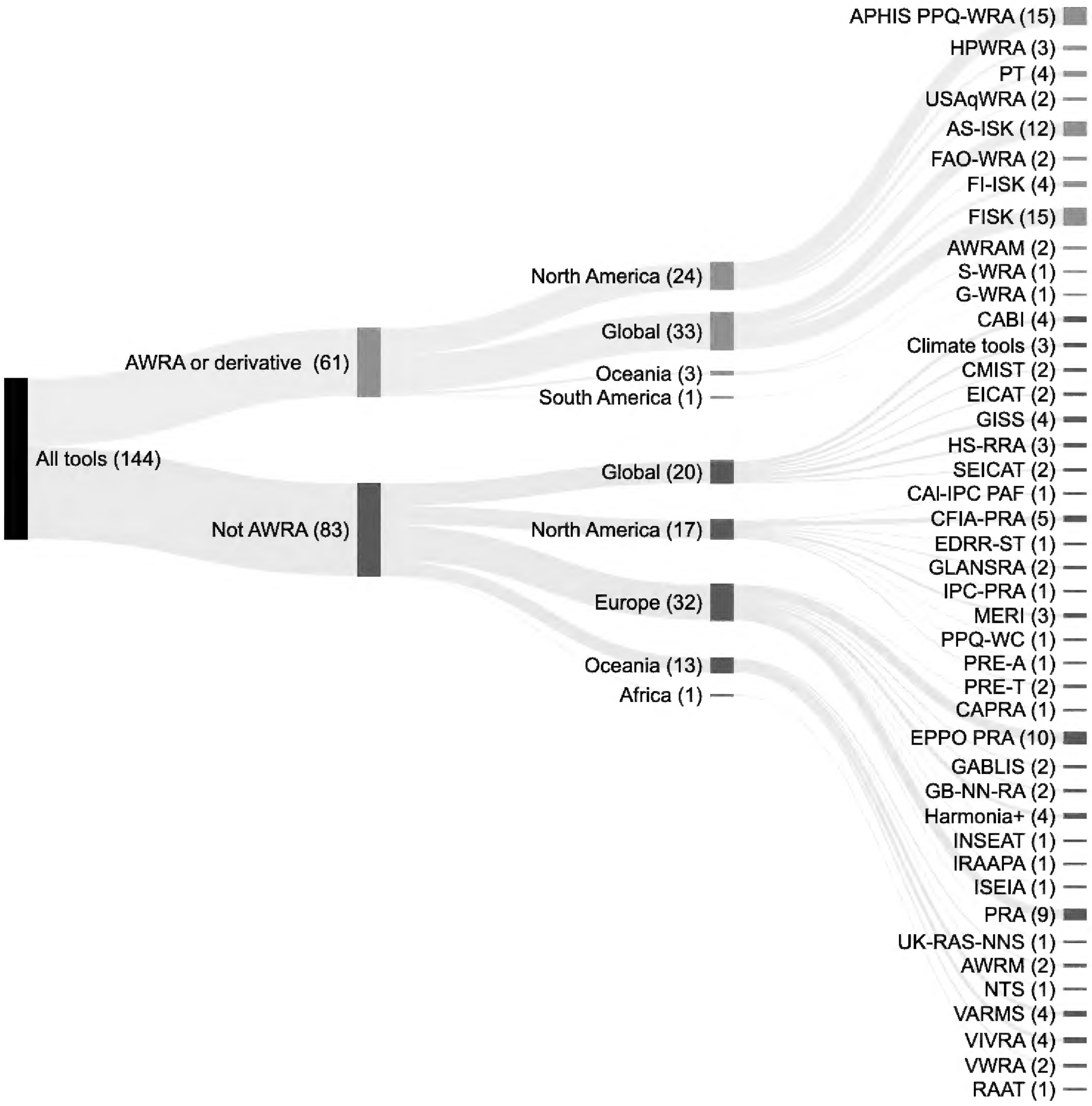

Figure 2. Hierarchical flow of risk assessment and risk analysis (collectively RA here) tools. The Sankey diagram illustrates the distribution of RA tools across four hierarchical levels. Starting from all tools (n=144), the flow divides at the first level by Weed Risk Assessment (AWRA) affiliation: tools that are either directly based on the original AWRA or derived from it (including indirect derivations, shown in orange), and those developed independently of the AWRA framework (non-AWRA tools, shown in green). The second level categorizes tools by the continent where they were developed and applied. The third level displays individual RA tool acronyms (see Table 2 for full names and references). The number in brackets at each node indicates the number of respondents who reported using that tool. Flow widths are proportional to the number of respondents, visually representing the relative usage of different pathways through the hierarchy. RA tools span a range of approaches, from rapid screening protocols to more comprehensive assessments involving impact categorization, pathway analysis, and related methods such as climate-based tools. Respondents reported using multiple RA tools.

Risk assessment methods and risk analysis (RA) tools

In total, respondents listed 46 different RAs that they have actively used (Fig. 2). Of these, at least five tools were direct implementations of the original Australian WRAs, which is possibly the best-known example of a RA for invasive species of any taxa (Kumschick and Richardson 2013; Lieurance et al. 2024; Fig. 2). An additional 11 tools were derived or modified versions of the Australian WRAs, directly or indirectly, including adaptations of the original tool for Armenia, Florida, the Galapagos, the Hawaiian Pacific, and Samoa. Modifications include changing the language of four questions related to climate and soil type to better reflect the conditions of the area at risk as well as to expand beyond plants (Gordon et al. 2008). However, other tools incorporate completely different approaches. Some were designed for speed and ease of completion such as the Horizon Scanning Rapid Risk Assessment (HS-RRA; e.g., Roy et al. 2014;

Lieurance et al. 2023) and the US Department of Agriculture's PPQ Weed Characterization Tool (PPQ-WC). Four tools evaluate impacts alone (EICAT, GISS, ISEIA and SEICAT) and climate matching tools were also mentioned (i.e., MaxEnt, Climatch), noting that these schemes assess either the likelihood of invasion or its consequences, they do not jointly assess both components of risk, and thus do not constitute full RAs (e.g., Kumschick et al. 2020a, 2024).

The RA tools most frequently reported by respondents, in terms of number of users, were the Fish Invasiveness Screening Kit (FISK) (Copp et al. 2009) and the Plant Protection and Quarantine Weed Risk Assessment (PPQ-WRA) (Koop et al. 2012), both adaptations of the Australian WRA System (Pheloung et al. 1999). The FISK is a global standard for evaluating the invasive potential of freshwater fish species. According to a global review by Vilizzi et al. (2019), FISK has been extensively applied in 45 countries, with 1973 RAs conducted by 70 experts across 372 taxa. There are two variations of the FISK mentioned in the responses, the FI-ISK or Freshwater Invertebrate Screening Kit and the AS-ISK or Aquatic Species Invasiveness Screening Kit. The AS-ISK is described as a generic screening tool which is applicable to any aquatic species and incorporates the minimum standards a RA scheme should include (Copp et al. 2016; Roy et al. 2018). The AS-ISK has effectively replaced five taxon-specific toolkits including the FISK and FI-ISK (Copp et al. 2016). This consolidation of ISK tools increases comparability across all aquatic taxa. Since this survey, the AS-ISK has been adapted (Vilizzi, Copp et al. 2022) to create the Terrestrial Animal Species Invasiveness Screening Kit (TAS-ISK) and the Terrestrial Plant Species Invasiveness Screening Kit (TPS-ISK).

In contrast, PPQ-WRA developed by the Animal and Plant Health Inspection Service (APHIS) for the U.S. Department of Agriculture (USDA), has a more limited geographic and taxonomic scope. Introduced in 2010, it assesses the likelihood of plants becoming weedy or invasive in the United States (including its territories) and incorporates some minimum standards outlined by Roy et al. (2018). As of 2024, it has been used for at least 163 species (APHIS 2023). While the PPQ-WRA has been used in a limited scope by states like Maryland, Michigan, and Nebraska and is currently implemented by the Canadian government as a part of their Canadian FIA Pest Risk Assessment (Anthony Koop Pers. Comm.), it has not been adopted outside North America.

Overall, a large number of RA tools were mentioned by respondents, with some categories having multiple tools available based on the same framework, as seen with weed (plant) RAs (Fig. 2). This variety of approaches reflects the challenge in RAs to balance locally relevant applications with broader tools that are comparable across regions (Kumschick et al. 2020b; Wilson et al. 2020). For example, some RAs take an idiographic approach and they assess risks on a case-by-case basis, such as the PPQ-WRA, which is relevant only within one country. In contrast, other assessment tools aim to be globally applicable and allow for generalizations. In general, there has been a growing sentiment among invasion scientists to have fewer frameworks that have consistent, broad-scale, and synthetic approaches to harmonize information and improve responses across different scales (Wilson et al. 2020). Wilson et al. (2020) recommended moving towards a hierarchy of frameworks that provides contextual details to help in selecting the most appropriate RA for a given objective. A good example of this is the development of the EICAT, which, while not strictly a RA on its own, has largely become the standard for categorizing environmental impact (Wilson et al. 2020).

Taxonomic scope of assessments

In terms of the taxonomic group most frequently assessed, plants were most commonly reported by respondents as the focus of their own assessments, with over 58% indicating that they evaluate plants in most or all of their assessments. This is significantly higher than for any other group (Fig. 3a). This emphasis on plants in individual respondents assessments may stem not only from potential research priorities but also from inherent mechanistic limitations in species-level RAs. For instance, species-level approaches are less applicable for many microbes, where detection and taxonomic identification are challenging. In cases of intentional introductions, the focus is naturally taxonomically biased. Pyšek et al. (2008) found that although nearly half of all studied invasive species were plants, they were less intensively researched than expected based on their relative numbers compared to non-native animal species in Europe. RAs were predominantly conducted for terrestrial taxa. In these environments, pathway-based risk analyses are likely more appropriate for guiding management (McGeoch et al. 2016). Nonetheless, aquatic and marine invasive species tend to be overlooked overall, often going unnoticed until impacts occur (Zaiko et al. 2014). In addition, RAs rely heavily on species-specific information, which can be difficult to obtain, especially for new or poorly studied species. The focus on certain taxonomic groups over others by invasion biologists has knock-on effects in monitoring and managing under-studied invaders, as groups that are overlooked in RAs often receive less taxonomic attention. Furthermore, the prevalence of plant-focused databases (Fig. 4) likely reinforces the heavier focus on plant invaders in RA efforts.

Data and information sources

Sourcing reliable data is essential for conducting an effective RA. Assessors often depend on specific databases to source and gather information to inform their assessments. These databases provide baseline data, distribution data, and survey data on establishment and spread of invasive species. They also provide data on impacts, environmental tolerances, and sometimes time since introduction or propagule pressure. We found that assessors rely on a wide variety of databases, with a total of 107 databases mentioned as frequently used by assessors for sourcing general (n = 43 databases), occurrence (n = 43), and taxonomic (n = 57) information, with some databases used for multiple categories. Many of these were repeatedly mentioned by different respondents (Fig. 4; For the full list see Suppl. material 1: table S2). The most commonly used general information databases were CABI's Invasive Species Compendium, the Global Invasive Species Database (GISD), the European Plant Protection Organisation (EPPO) Global Database, the Global Compendium of Weeds (GCW), and Delivering Alien Invasive Inventories for Europe (DAISIE). When obtaining species occurrence records, respondents primarily relied on the Global Biodiversity Information Facility (GBIF), CABI's Invasive Species Compendium, iNaturalist, EDDMapS (Early Detection and Distribution Mapping System), and the Global Register of Introduced and Invasive Species (GRIIS). The Integrated Taxonomic Information System (ITIS) and Tropicos were the most commonly used taxonomic databases, along with more specialized resources such as FishBase,

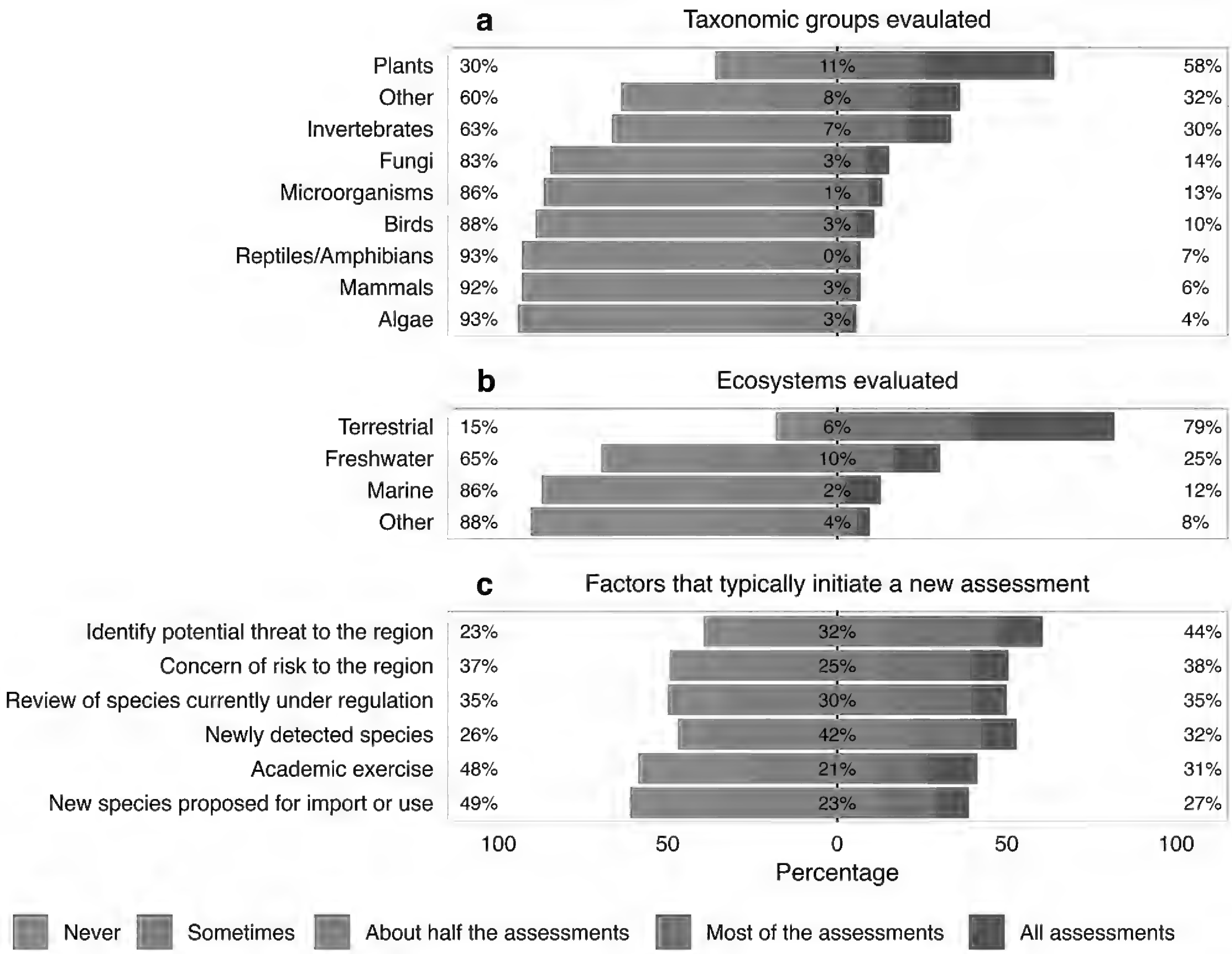

Figure 3. The survey responses regarding the evaluation of taxonomic groups, ecosystems, and factors that prompt new risk assessments or risk analyses (collectively RAs here). Answers were provided on a 5-point Likert scale with the categories: never, sometimes, about half of RAs, most of RAs, all RAs. Each plot represents the proportion of respondents who indicated the extent to which they assess specific groups, ranging from 'None' (red; left-hand side) to 'All RAs' (green; right-hand side). The percentages on the left side of each plot indicate the proportion of responses for lower frequency categories ('None' and 'Sometimes'), the middle percentages reflect 'About half of RAs', and the right side shows the percentage of higher frequency responses ('Most of RAs' and 'All RAs'). Categories are cantered at 0% on the x-axis, and the width of each bar reflects the relative percentage of respondents for each category, summing up to 100%.

the International Plant Names Index (IPNI), the World Register of Marine Species (WoRMS), The Plant List, and World Flora Online. The most frequently used databases are primarily managed by academic or research institutions (40 databases), government agencies (36), non-profit organizations (36), and intergovernmental entities (23). Of these databases, 43% provided global data.

Of the databases mentioned, 94.4% (101 out of 107) are open access, meaning that their data are freely available (Suppl. material 1: table S2 for a list of databases). The higher utilization of open-access resources is perhaps expected as they tend to be easier to access and do not require funding to use. This shift to open data has likely further increased since this study, as, since the COVID-19 pandemic there has been widespread change in how researchers disseminate their results, more often seeking open access options (Waltman et al. 2021). The shift towards open access aligns with the principles of the FAIR system (Findable, Accessible, Interoperable, and Reusable), which aims to improve the infrastructure

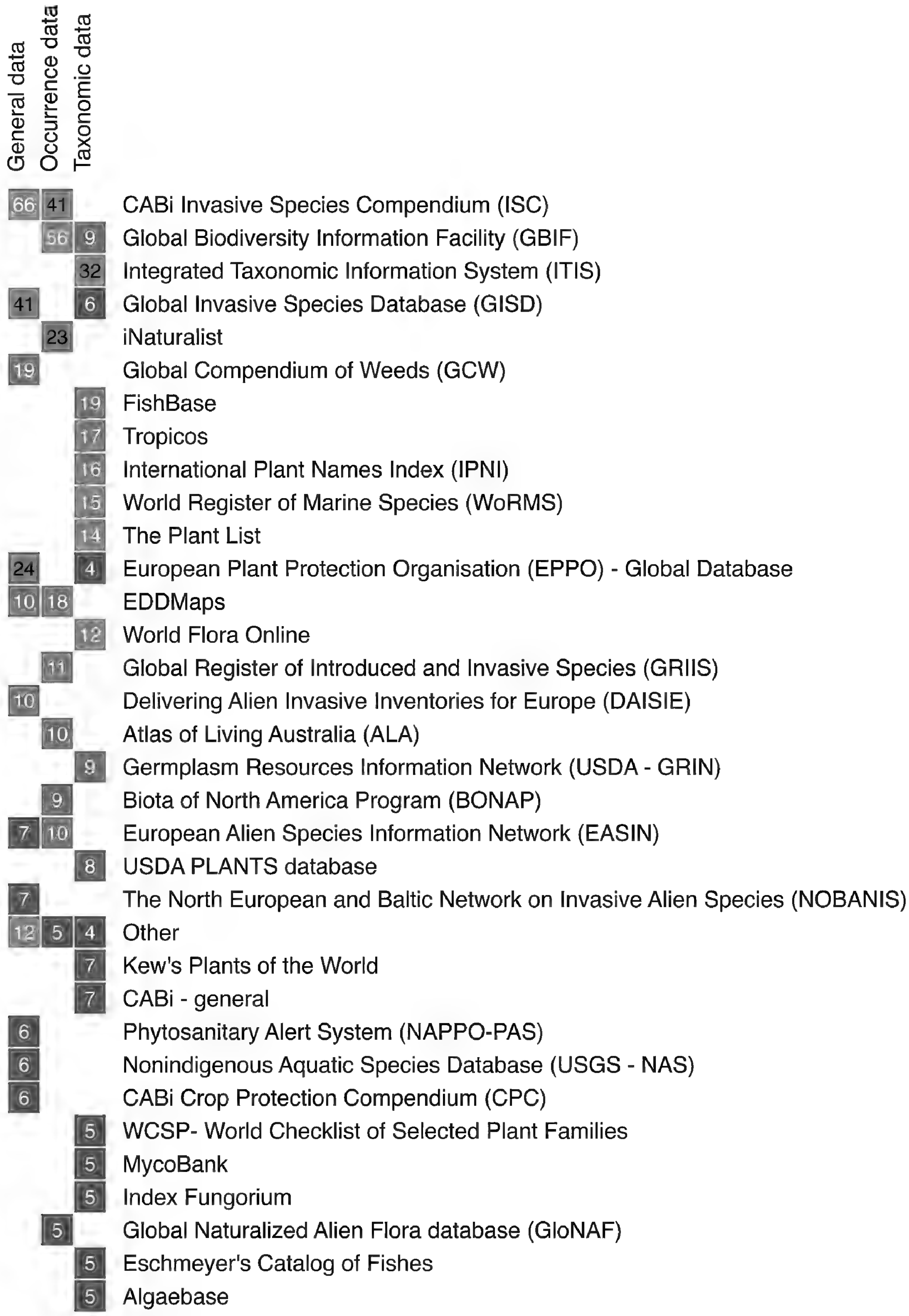

Figure 4. Most frequently used databases by respondents for risk assessments and risk analyses (collectively RAs), categorized by their purpose in gathering general, occurrence, or taxonomic information. The number of respondents is shown in each box, with a colour gradient from green for low numbers to red for high numbers. Only databases mentioned by five or more respondents are included in this figure (See Suppl. material 1: table S2 for the full list of 107 databases mentioned).

supporting the reuse of scholarly data. However, it is important to note that some databases, while open, are poorly managed or no longer updated, resulting in outdated information. This poses a significant challenge, as reliance on outdated data can compromise the accuracy and effectiveness of RAs. We encourage the use of primary data whenever possible, as much of the information in some databases is not underpinned by traceable evidence, making it difficult to verify its accuracy.

Data limitations

Uncertainty is an inherent part of RAs, which are often designed to evaluate and account for it to the extent possible. There are many stages of the process in which uncertainty can impact the results, such as human error in the data, incomplete information searches, species misidentification, insufficient survey data, or resolution issues in data scaling (McGeoch et al. 2016; Probert et al. 2020). Additionally, assessors may have a lack of knowledge or face limitations in accessing data, leading to low confidence in the final risk outputs. Despite these uncertainties, decisions regarding the management and prevention of invasive species must still be made. Reporting the sources of uncertainty in RAs helps stakeholders understand the limitations of any given assessment (McGeoch et al. 2016). As such, Roy et al. (2018) recommend that acknowledging data limitations should be a standard in RAs, by providing a statement or score indicating the assessor's confidence level in the quality and reliability of the data/information. Encouragingly, we found that a very high proportion (93.2%) of assessors said they incorporate uncertainty or confidence, with three out of four always doing so.

Evaluation of assessment

A peer-review process is crucial in evaluating the scientific rigour, accuracy, and validity of data, methodologies, and conclusions in RAs (Warren et al. 2017). There are growing calls to make peer-review standard practice, facilitating feedback between assessors and reviewers to mitigate inherent biases. Our study found that 88% of respondents said assessments include some form of peer review, and 61% reported that peer review is consistently integrated. The type of peer review matters as well: whether it is internal (e.g., conducted within an organization) or external (e.g., involving independent experts) may influence the objectivity of the evaluation process (Hill et al. 2020). Among assessors who conduct peer reviews of assessments (n = 85), 42% used a combination of internal and external review, 17% exclusively used external peer review, and 40% relied solely on internal review.

While expert-based RA is common, the incorporation of external comment and consensus-building approaches is notably rare, as evidenced by the lack of documentation on these practices in the literature. When stakeholders (e.g., commercial importers, land managers) are involved in the decision-making process, there is a higher likelihood of successful implementation of management measures, as those affected by the outcomes feel a sense of ownership and responsibility (Reis et al. 2013). However, our findings highlight how input from stakeholders is integrated into RAs, suggesting that key parties are rarely engaged even at the assessment stage, let alone in the broader decision-making process. In 41% of the cases reported by assessors (n = 30), public comment was absent from their RAs, while only 20% consistently incorporated it, and 29% included it occasionally or infrequently.

Despite these variations, a majority of assessors indicated that their final RAs are publicly accessible, with 40% affirming consistent availability, 37.2% reporting occasional or rare accessibility, 14% expressing uncertainty, and 9.4% stating their assessments were never accessible.

Experience, qualifications of assessors and training

The survey respondents predominantly held graduate degrees, with nearly 90% holding master's (24%) or doctoral degrees (64%). Only 3.1% did not possess a tertiary degree. In terms of experience in conducting RAs, the respondents had variable levels of expertise. Roughly a third of respondents (34%) had at least a decade of experience, and a quarter had five to ten years (26%). However, a notable proportion (44%) reported conducting fewer than ten RAs over the last three years. The next largest cohorts, those who conducted between 11 and 50 RAs and those who completed more than 50 assessments, accounted for 34% and 22.4% of the responses, respectively. Finally, 8.4% of respondents were highly experienced, having conducted over 100 RAs.

Regarding the qualifications needed for a risk assessor, while 64% of respondents held doctorate degrees, only 3% believe that a PhD is necessary to conduct assessments proficiently. Most respondents consider tertiary education sufficient, with 41% citing a bachelor's degree and 37% a master's degree as the minimum requirements. This suggests that it may not be necessary to rely exclusively on assessors with doctoral degrees for RAs; instead, agencies and organizations responsible for RAs should focus on providing appropriate training and support to ensure assessor competence. Academic scientists are frequently overwhelmed by additional administrative and peripheral tasks, which detracts from their ability to focus on research. This has been found to lead to exhaustion and high levels of burnout and have resulted in calls to adjust the management of academic work. Since a majority of assessors had completed fewer than ten assessments, RA may not be a primary job responsibility. Therefore, delegating RAs to dedicated and trained assessors could enhance efficiency, cost-effectiveness, and potentially consistency. However, this approach should be evaluated individually, as the complexity of RAs can vary between schemes, with some requiring less interpretation of scientific studies and more focus on collecting information on traits.

We also identified a significant gap in formal training programs and certification for structured education designed to train assessors in conducting RAs. A majority of respondents (73.2%) indicated strong support for implementing a training or certification program as a prerequisite for assessors. A large portion of respondents (35%) believed that 17–40 hours of training (up to a week) were required to become proficient at conducting a typical RA, while many (23%) indicated that up to a month (40–160 hours) might be necessary. Few respondents suggested that more than a month of training was needed, indicating that a full college-term course is unnecessary. However, a short workshop (lasting only a few days or a week) would be insufficient. Therefore, the optimal length of the course would be between a week and a month. Even with such training, working alongside or having assessments reviewed by a more experienced assessor would likely be beneficial initially.

Some organizations already provide training programs, though these efforts are not widespread. For instance, in the European Union, EPPO has provided courses on pest risk analysis of invasive alien plant species as per the requirements of certain EU regulations. Similarly, South Africa developed a risk analysis training course in 2018, which has since certified 52 participants across 19 courses as of April 2024 (Wilson and Kumschick 2024). The capacity for training even on limited budgets is more realistic now with the advent of e-Learning tools. Many agencies have shown the value and ease to which online training is possible such

as the 'Better Biosecurity e-Learning course' designed by the University of Leeds, Environment Agency (Shannon et al. 2020). Research has shown that online training can provide an effective alternative to face-to-face training in higher education and achieve the same performance (Azeiteiro et al. 2015).

These results suggest that programs to train risk assessors should focus on individuals with at least a bachelor's degree. However, this conclusion should be interpreted with caution and considered on a case-by-case basis, as the feedback is heavily influenced by perspectives from the global North. For example, in South Africa, the Alien Species Risk Analysis Review Panel (ASRARP)—which provides independent scientific advice to the Department of Forestry, Fisheries and the Environment (DFFE)— found that assessors with at least an MSc degree or some experience authoring a peer-reviewed publication (and in particular with responding to reviewer comments) had the necessary skills to draft and revise risk analyses (Kumschick and Wilson personal observations).

Initiating, reporting and implementing

When asked which factors initiate a RA, the responses were distributed relatively evenly across all options, suggesting there are a variety of triggers, such as regulatory requirements, stakeholder concerns, or emerging threats (Fig. 3).

We found that a large portion of RAs are reported to higher authorities, with nearly half (n = 71; 48%) reported to government agencies and a third (n = 43; 29%) to university or research institutions. Fewer RAs were directed to non-profit/non-governmental organizations (n = 16; 11%), private consultancies (n = 7; 4.7%), and other organizations (n = 11; 7.4%). This distribution is consistent with Roy et al. (2018), who noted that government agencies and research institutions are primary stakeholders in the utilization of RAs for policy development and implementation. However, there are examples of non-governmental organizations developing RAs (e.g., The Nature Conservancy helped to develop the IFAS Assessment to prioritize both management and advocacy effort; Gordon et al. 2008).

There is a need for standardization in terminology, methods, and criteria for RAs to reduce inconsistencies and uncertainties in outcomes, particularly crucial for regions with limited funding capacity (Roy et al. 2018). The development of multiple tools tailored to specific taxa, regions, and habitats, along with the use of jargon and acronyms, pose significant barriers to the effectiveness of RAs as decision-support tools. The proliferation of different tools at varying scales can hinder the discipline's ability to track broader and regional-scale patterns effectively. However, country-specific requirements for RAs often necessitate tailored approaches. While having a single standardized framework could facilitate comparisons and information-sharing across regions, it might not serve the needs of specific policy- and decision-makers. Country-specific adaptations are often necessary to align with local regulations and management priorities.

Recommendations

Based on the views expressed by the responders to the survey, we identified five broad areas where people felt specific focus is important for RAs and eleven specific recommendations.

1. Training and capacity building
    1.1. Standardised qualifications: training or certification programs are important to ensure practitioners possess the necessary skills and knowledge.
    1.2. Minimum requirements: while a specific undergraduate degree or post-graduate degree might not be needed, scientific literacy is an essential pre-requisite for RA training to be effective; in practice, most people conducting RA have at least an MSc.
    1.3. Course duration: training courses probably need to be between one week and one month, ideally including a practical component.
2. Databases and information sources
    2.1. Facilitate access: Utilize open-access databases and other sources to ensure researchers, policymakers, and stakeholders can access critical data without financial or institutional barriers.
    2.2. Data sharing: improve the quality of RAs by promoting data sharing, especially for new or understudied invasive species
3. Cooperation and standardization of tools
    3.1. Reduce duplication: Establish mechanisms for data sharing, collaborative RAs, and mutual recognition of assessments across regions to minimize duplicated efforts, particularly in resource-limited regions.
    3.2. A common framework: if a similar basic framework is used, data can be shared among regions and countries, while still recognising the need for country-specific requirements and regulations.
4. Communication of results
    4.1. Specify the rationale: Clearly explain why each RA was initiated to enhance stakeholder understanding.
    4.2. Incorporate uncertainty: Ensure RAs include measures of uncertainty to support informed decision-making.
    4.3. Raise awareness: the communication of RA results need to be in a clear and effective manner to boost awareness of invasive species risks and encourage support for necessary interventions among stakeholders
5. Open access
    5.1. Enhance transparency and accountability: Provide access to completed RAs where possible. Transparency will allow stakeholders to understand the basis for recommendations, identify knowledge gaps, and ensure the RA process is based on the best available evidence.

Acknowledgements

We sincerely thank Sam Scherneck for their valuable contributions to this research.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

Funding

This work is/was supported by the USDA National Institute of Food and Agriculture and Hatch Appropriations under Project #PEN05000 and Accession #7008007. JRUW and SK thank the South African Department of Forestry, Fisheries and the Environment (DFFE) for funding, noting that this publication does not necessarily represent the views or opinions of DFFE or its employees.

Author contributions

SC and DL conceived the ideas; SC and DL distributed the survey and collected the data; SC analysed the data. SC and DL led the writing of the manuscript with help from KC, SK, DRG, JRUW. All authors contributed critically to the drafts and gave final approval for publication.

Author ORCIDs

Susan Canavan https://orcid.org/0000-0002-7972-7928
Kim Canavan https://orcid.org/0000-0001-7353-6613
Sabrina Kumschick https://orcid.org/0000-0001-8034-5831
Doria R. Gordon https://orcid.org/0000-0001-6398-2345
John R. U. Wilson https://orcid.org/0000-0003-0174-3239
Deah Lieurance https://orcid.org/0000-0001-8176-3146

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

References

Animal and Plant Health Inspection Service (APHIS) (2024) Noxious Weeds Program Risk Assessments. APHIS. https://www.aphis.usda.gov/plant-pests-diseases/noxious-weeds/noxious-weeds-program-risk-assessments [accessed 19 July 2024]

Azeiteiro UM, Bacelar-Nicolau P, Caetano FJ, Caeiro S (2015) Education for sustainable development through e-learning in higher education: experiences from Portugal. Journal of Cleaner Production 1(106): 308–319. https://doi.org/10.1016/j.jclepro.2014.11.056

Bacher S, Blackburn T, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul WC, Scalera R, Vila M, Wilson JRU, Kumschick S (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9(1): 159–168. https://doi.org/10.1111/2041-210X.12844

Baker RHA, Black R, Copp GH, Haysom KA, Hulme PE, Thomas MB, Brown A, Brown M, Cannon RJC, Ellis J, Ellis E, Ferris R, Glaves P, Gozlan RE, Holt H, Howe L, Knight JD, MacLeod A, Moore NP, Mumford JD, Murphy ST, Parrott D, Sansford CE, Smith GC, St-Hilaire S, Ward NL (2008) The UK risk assessment scheme for all non-native species. NeoBiota 7: 46–57.

Bomford M (2008) Risk assessment models for the establishment of exotic vertebrates in Australia and New Zealand. Invasive Animals Cooperative Research Centre, Canberra, Australia.

Branquart E [Ed.] (2007) Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium, Version 2.5.

Brunel S, Branquart E, Fried G, van Valkenburg J, Brundu G, Starfinger U, Buholzer S (2010) The EPPO prioritization process for invasive alien plants. Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation 40(3): 407–422. https://doi.org/10.1111/j.1365-2338.2010.02423.x

CABI (2019) Pest Risk Analysis Tool. https://www.cabi.org/PRA-Tool/signin?returnUrl=%2FPRA-Tool%2F

Cal-IPC (n.d.) Cal-IPC Weed Risk Assessment. https://www.cal-ipc.org/solutions/research/riskassessment/

Canadian Food Inspection Agency (2020) Pest Risk Analysis: How we evaluate fruits, vegetables and plants from new countries of origin. https://inspection.canada.ca/plant-health/horticulture/imports/how-we-evaluate/eng/1425496755404/1425496838700

Champion PD, Clayton JS (2000) Border control for potential aquatic weeds. Department of Conservation, New Zealand.

Conser C, Seebacher L, Fujino DW, Reichard S, DiTomaso JM (2015) The development of a Plant Risk Evaluation (PRE) Tool for assessing the invasive potential of ornamental plants. PLoS ONE 10(3): e0121053. https://doi.org/10.1371/journal.pone.0121053

Copp GH, Garthwaite R, Gozlan RE (2005) Risk identification and assessment of non-native freshwater fishes: concepts and perspectives for the UK. CEFAS Science Series Technical Report 129, 32 pp.

Copp GH, Vilizzi L, Mumford J, Fenwick GV, Godard MJ, Gozlan RE (2009) Calibration of FISK, an invasiveness screening tool for nonnative freshwater fishes. Risk Analysis 29(3): 457–467. https://doi.org/10.1111/j.1539-6924.2008.01159.x

Copp GH, Vilizzi L, Tidbury H, Stebbing PD, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 7(4): 343–352. https://doi.org/10.3391/mbi.2016.7.4.04

D'hondt B, Vanderhoeven S, Roelandt S, Mayer F, Versteirt V, Adriaens T, Ducheyne E, San Martin G, Grégoire JC, Stiers I, Quoilin S, Cigar J, Heughebaert A, Branquart E (2015) Harmonia+ and Pandora+: Risk screening tools for potentially invasive plants, animals, and their pathogens. Biological Invasions 17: 1869–1883. https://doi.org/10.1007/s10530-015-0843-1

Daehler CC, Denslow JS, Ansari S, Kuo HC (2004) A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific islands. Conservation Biology 18(2): 360–368. https://doi.org/10.1111/j.1523-1739.2004.00066.x

Davidson AD, Fusaro AJ, Sturtevant RA, Kashian DR (2017) Development of a risk assessment framework to predict invasive species establishment for multiple taxonomic groups and vectors of introduction. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 8(1): 25–36. https://doi.org/10.3391/mbi.2017.8.1.03

Dean EM, Jordon A, Agnew AC, Hernandez ND, Morningstar CR, Neilson M, Piccolomini SE, Reichert B, Wray AK, Daniel WM (2024) America's Most Wanted Fishes: Cataloging risk assessments to prioritize invasive species for management action. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 15(1): 1–20. https://doi.org/10.3391/mbi.2024.15.1.01

Drolet D, DiBacco C, Locke A, McKenzie CH, McKindsey CW, Moore AM, Therriault TW (2016) Evaluation of a new screening-level risk assessment tool applied to non-indigenous marine invertebrates in Canadian coastal waters. Biological Invasions 18: 279–294. https://doi.org/10.1007/s10530-015-1008-y

EPPO (2011) Guidelines on Pest Risk Analysis: Decision-support scheme for quarantine pests. European and Mediterranean Plant Protection Organization. http://archives.eppo.org/EPPOStandards/pra.html [accessed 21 June 2024]

EPPO (2019) EPPO Technical Document No. 1079, Review of EPPO's approach to Pest Risk Analysis. EPPO, Paris.

EPPO (2024) EPPO Platform on PRAs. European and Mediterranean Plant Protection Organization. https://pra.eppo.int/ [accessed 21 June 2024]

Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C, Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing the German-Austrian Black List Information System (GABLIS). Journal for Nature Conservation 19: 339–350. https://doi.org/10.1016/j.jnc.2011.08.005

FAO (2007a) Glossary of Phytosanitary Terms. International Standards for Phytosanitary Measures No. 5. IPPC-FAO, Rome, Italy.

FAO (2007b) Framework for Pest Risk Analysis. International Standards for Phytosanitary Measures No. 2. IPPC-FAO, Rome, Italy.

Fayvush G, Vardanyan Z, Aleksanyan A (2018) Invasiveness risk assessment of woody plants of Armenia. Thaiszia -. Le Journal de Botanique 28(2): 81–91.

Gantz CA, Gordon DR, Jerde CL, Keller RP, Chadderton WL, Champion PD, Lodge DM (2015) Managing the introduction and spread of non-native aquatic plants in the Laurentian Great Lakes: A regional risk assessment approach. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 6(1): 45–55. https://doi.org/10.3391/mbi.2015.6.1.04

Ginn J, Curtis J, Jackson S, Kaminsky S, Knudsen E, O'Brien J, Seneca D, Silge J, Wong P (2024) qualtRics: Download 'Qualtrics' Survey Data (Version 3.2.0) [R package]. https://CRAN.R-project.org/package=qualtRics

Gordon DR, Onderdonk DA, Fox AM, Stocker RK, Gantz C (2008) Predicting invasive plants in Florida using the Australian Weed Risk Assessment. Invasive Plant Science and Management 1: 178–195. https://doi.org/10.1614/IPSM-07-037.1

Gordon DR, Gantz CA, Jerde CL, Chadderton WL, Keller RP, Champion PD (2012) Weed risk assessment for aquatic plants: Modification of a New Zealand system for the United States. PLoS ONE 7(7): e40031. https://doi.org/10.1371/journal.pone.0040031

Government of New Zealand MPI (2020) Biosecurity Science and Risk Assessment Procedures: Import Risk Analysis Overview.

Gozlan DR, Burnard D, Andreou D, Britton JR (2013) Understanding the threats posed by non-native species: public vs. conservation managers. PLoS ONE 8(1): e53200. https://doi.org/10.1371/journal.pone.0053200

Griessinger D, Baker RHA, Black R, Breukers A, Brunel S, Holt J, et al. (2012) CAPRA: The EPPO computer-assisted PRA scheme. Bulletin OEPP. EPPO Bulletin. European and Mediterranean Plant Protection Organisation 42(1): 42–47. https://doi.org/10.1111/j.1365-2338.2012.02541.x

Hawkins CL, Bacher S, Essl F, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Vilà M, Wilson JRU, Genovesi P, Blackburn TM (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). Diversity & Distributions 21(11): 1360–1363. https://doi.org/10.1111/ddi.12379

Hill JE, Copp GH, Hardin S, Lawson KM, Marcot BG (2020) Comparing impacts of invasive species risk assessment frameworks: Response to Marcot et al. (2019) Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 11(2): 325–341. https://doi.org/10.3391/mbi.2020.11.2.10

Koop A (2012) Special applications of pest risk analysis—weed risk assessment. In: Devorshak C (Ed.) Plant Pest Risk Analysis: Concepts and Application. CABI, Wallingford, 237–255. https://doi.org/10.1079/9781780640365.0237

Koop AL, Fowler L, Newton LP, Caton BP (2012) Development and validation of a weed screening tool for the United States. Biological Invasions 14(2): 273–294. https://doi.org/10.1007/s10530-011-0061-4

Kumschick S, Richardson DM (2013) Species-based risk assessments for biological invasions: Advances and challenges. Diversity & Distributions 19: 1095–1105. https://doi.org/10.1111/ddi.12110

Kumschick S, Bacher S, Bertolino S, Blackburn TM, Evans T, Roy HE, Smith K (2020a) Appropriate uses of EICAT protocol, data and classifications. NeoBiota 62: 193–212. https://doi.org/10.3897/neobiota.62.51574

Kumschick S, Wilson JR, Foxcroft LC (2020b) A framework to support alien species regulation: The Risk Analysis for Alien Taxa (RAAT). NeoBiota 62: 213–239. https://doi.org/10.3897/neobiota.62.51031

Kumschick S, Bertolino S, Blackburn TM, Brundu G, Costello KE, De Groot M, Bacher S (2024) Using the IUCN Environmental Impact Classification for Alien Taxa to inform decision-making. Conservation Biology 38(2): e14214. https://doi.org/10.1111/cobi.14214

Leung B, Roura-Pascual N, Bacher S, Heikkilä J, Brotons L, Burgman MA, Vilà M (2012) TEASIng apart alien species risk assessments: A framework for best practices. Ecology Letters 15: 1475–1493. https://doi.org/10.1111/ele.12003

Lieurance D, Canavan S, Behringer DC, Kendig AE, Minteer CR, Reisinger LS, Romagosa CM (2023) Identifying invasive species threats, pathways, and impacts to improve biosecurity. Ecosphere 14(12): e4711. https://doi.org/10.1002/ecs2.4711

Lieurance D, Culley T, Brand M, Canavan S, Daehler C, Evans C, Keller R (2024) Preventing the next plant invasion: Opportunities and challenges. Council for Agricultural Science and Technology (CAST). Issue Paper 73. CAST, Ames, Iowa.

Mandujano MC, Golubov FJ, Sifuentes SI, Salomé DJ, Bayona CA (2021) Adaptación y evaluación de riesgo utilizando métodos estandarizados para especies de plantas exóticas invasoras en México. Universidad Nacional Autónoma de México, Instituto de Ecología. Informe Final. SNIB-CONABIO. Proyecto No. RE001. Ciudad de México.

Martinez-Cillero R, Willcock S, Perez-Diaz A, Joslin E, Vergeer P, Peh KSH (2019) A practical tool for assessing ecosystem services enhancement and degradation associated with invasive alien species. Ecology and Evolution 9(7): 3918–3936. https://doi.org/10.1002/ece3.5020

McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biological Invasions 18: 299–314. https://doi.org/10.1007/s10530-015-1013-1

Nentwig W, Bacher S, Pyšek P, Vilà M, Kumschick S (2016) The Generic Impact Scoring System (GISS): A standardized tool to quantify the impacts of alien species. Environmental Monitoring and Assessment 188: 315. https://doi.org/10.1371/journal.pbio.1001850

Nuñez MA, Chiuffo MC, Seebens H, Kuebbing S, McCary MA, Lieurance D, Zhang B, Simberloff D, Meyerson LA, (2022) Two decades of data reveal that Biological Invasions needs to increase participation beyond North America, Europe, and Australasia. Biological Invasions. Biological Invasions 1: 1–8. https://doi.org/10.1007/s10530-021-02666-6

Pheloung PC, Williams PA, Halloy SR (1999) A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57(4): 239–251. https://doi.org/10.1006/jema.1999.0297

Probert AF, Volery L, Kumschick S, Vimercati G, Bacher S (2020) Understanding uncertainty in the Impact Classification for Alien Taxa (ICAT) assessments. NeoBiota 62: 387–405. https://doi.org/10.3897/neobiota.62.52010

Pyšek P, Richardson DM, Pergl J, Jarošík V, Sixtová Z, Weber E (2008) Geographical and taxonomic biases in invasion ecology. Trends in Ecology & Evolution 23(5): 237–244. https://doi.org/10.1016/j.tree.2008.02.002

Reis CS, Marchante H, Freitas H, Marchante E (2013) Public perception of invasive plant species: Assessing the impact of workshop activities to promote young students' awareness. International Journal of Science Education 35(4): 690–712. https://doi.org/10.1080/09500693.2011.610379

Rogg H, Buddenhagen C, Causton C (2003) Experiences and limitations with pest risk analysis in the Galapagos Islands. In Identification of risks and management of invasive alien species using the IPPC framework: Proceedings of the workshop on invasive alien species and the International Plant Protection Convention, 1–8.

Romagosa CM (2018) Greater Everglades Ecosystem Rapid Response Screening Tool (GEERReST). User guide and Executive summary for Committee on Independent Scientific Review of Everglades Restoration Progress.

Roy HE, Peyton J, Aldridge DC, Bantock T, Blackburn TM, Britton R, Walker KJ (2014) Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. Global Change Biology 20(12): 3859–3871. https://doi.org/10.1111/gcb.12603

Roy HE, Rabitsch W, Scalera R, Stewart A, Gallardo B, Genovesi P, Zenetos A (2018) Developing a framework of minimum standards for the risk assessment of alien species. Journal of Applied Ecology 55(2): 526–538. https://doi.org/10.1111/1365-2664.13025

Shannon JC, Stebbing PD, Quinn CH, Warren DA, Dunn AM (2020) The effectiveness of e-Learning on biosecurity practice to slow the spread of invasive alien species. Biological Invasions 22: 2559-71. https://doi.org/10.1007/s10530-020-02271-z

Space JC, Flynn T (2000) Observations on invasive plant species in American Samoa. USDA Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry.

Tricarico E, Vilizzi L, Gherardi F, Copp GH (2010) Calibration of FI-ISK, an invasiveness screening tool for nonnative freshwater invertebrates. Risk Analysis. International Journal (Toronto, Ont.) 30(2): 285–292. https://doi.org/10.1111/j.1539-6924.2009.01255.x

USDA APHIS PPQ [United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine] (2020) WI E-522 Imported Plant Commodity Pest Risk Assessment Framework. Plant Epidemiology and Risk Analysis Laboratory. https://www.aphis.usda.gov/sites/default/files/imported-plant-commodity-pra-framework.pdf

Vilizzi L, Copp GH, Adamovich BV, Almeida D, Chan J, Davison PI, Zeng Y (2019) A global review and meta-analysis of applications of the freshwater fish invasiveness screening kit. Reviews in Fish Biology and Fisheries 29(3): 529–568. https://doi.org/10.1007/s11160-019-09562-2

Vilizzi L, Hill JE, Piria M, Copp GH (2022) A protocol for screening potentially invasive non-native species using Weed Risk Assessment-type decision-support tools. Science of the Total Environment 832: 154966. https://doi.org/10.1016/j.scitotenv.2022.154966

Virtue JG (2010) South Australia's Weed Risk Management System. Plant Protection Quarterly 25(2): 90–94. https://search.informit.org/doi/10.3316/informit.137773171097151

Waltman L, Pinfield S, Rzayeva N, Henriques SO, Fang Z, Brumberg J, Swaminathan S (2021) Scholarly communication in times of crisis. Research on Research Institute, Report No. 10. https://doi.org/10.6084/m9.figshare.17125394

Warren RJ, King JR, Tarsa C, Haas BJ, Henderson JS (2017) A systematic review of context bias in invasion biology. PLoS ONE 12(8): e0182502. https://doi.org/10.1371/journal.pone.0182502

Weiss J, McLaren D, Edgar R (2002) Victoria's pest plant prioritisation process. In: Jacob HS, Dodd J, Moore JH (Eds) Proceedings of the 13th Australian Weeds Conference. Plant Protection Society of Western Australia, 509–512.

Williams PA (2002) Proposed guidelines for weed risk assessment in developing countries. Expert Consultation on Weed Risk Assessment.

Wilson JR, Kumschick S (2024) The regulation of alien species in South Africa. South African Journal of Science 120(5–6): 1–4. https://doi.org/10.17159/sajs.2024/17002

Wilson JR, Bacher S, Daehler CC, Groom QJ, Kumschick S, Lockwood JL, Richardson DM (2020) Frameworks used in invasion science: Progress and prospects. NeoBiota 62: 1–30. https://doi.org/10.3897/neobiota.62.58738

Zaiko A, Minchin D, Olenin S (2014) "The day after tomorrow": Anatomy of an 'r' strategist aquatic invasion. Aquatic Invasions 9(2): 145–155. https://doi.org/10.3391/ai.2014.9.2.03

Supplementary material 1

Additional information

Authors: Susan Canavan, Kim Canavan, Sabrina Kumschick, Doria R. Gordon, John R.U.Wilson, Deah Lieurance

Data type: pdf

Explanation note: **table S1.** Survey questions. **table S2.** Databases used. Databases most frequently used to inform risk assessments, organised by their specific use for taxonomic (teal), general (green) or occurrence data (orange). Some databases are repeated and used for different purposes. Additionally, the table includes the number of respondents who reported using each database for that purpose (denoted as "n") and whether it has open online access. **table S3.** Summarised results of multiple choice question.

Link: https://doi.org/10.3897/neobiota.99.153010.suppl1